International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
SJIF (2024): 6.623

Flood Early Warning Systems Using IoT Telemetry: A Review of System Components and Applications

Samuel M. Nyaanga[1*], Duncan. Mbuge D. [1], Abraham Nyete[1]

[1]University of Nairobi

*Corresponding author: samnyaanga[at]gmail.com

Abstract: ***Flood disasters are increasing globally due to climate change, rapid urbanization, and unsustainable land use. Traditional flood monitoring approaches often fail to provide timely warnings, particularly in developing countries. The emergence of Internet of Things (IoT)-enabled Flood Early Warning Systems (FEWS) offers transformative potential by integrating real-time sensors, telemetry networks, cloud-based data processing, and multi-channel alert dissemination. This paper presents a systematic review of global and Kenya-specific applications of IoT telemetry in FEWS, highlighting system components, implementation strategies, challenges, and opportunities. Key components discussed include hydrological and meteorological sensors, communication technologies such as GSM, LoRaWAN, and satellite telemetry, data analytics and predictive models, and alert dissemination platforms. Lessons from pilot deployments in Kenya's Tana River, Nyando, and Nairobi River catchments illustrate improvements in lead time, situational awareness, and community preparedness. Challenges such as connectivity gaps, high costs, and limited technical capacity are identified, alongside opportunities for low-cost, sustainable sensor networks and integration with predictive analytics. The study concludes with recommendations to enhance IoT-enabled FEWS in Kenya and similar developing countries, promoting resilient flood management infrastructure and informed disaster response.***

Keywords: Data Analytics, Disaster Risk Reduction, Flood Early Warning Systems, IoT telemetry, Real-time Monitoring, Sensors, Telemetry Networks, Predictive Flood Modelling

Highlights

Paper presents systematic review of IoT-enabled Flood Early Warning Systems (FEWS) including:

- Key system components including sensors, telemetry networks, data analytics, and multi-channel alert dissemination.
- Global and Kenya-specific case studies
- Major challenges in IoT FEWS deployment, including connectivity gaps, cost, and technical capacity limitations.
- Opportunities for low-cost, sustainable, and community-integrated flood monitoring systems.
- Actionable recommendations to enhance flood resilience and disaster preparedness in Kenya and similar developing countries.

1.Introduction

Flood disasters have intensified in frequency and magnitude globally due to the combined effects of climate change, rapid urbanization, and unsustainable land-use practices [10]. Traditional flood monitoring and warning approaches, which depend on manual measurements and delayed data reporting, often fail to provide communities with sufficient lead time for evacuation and mitigation [18]. Consequently, there is a growing need for innovative and real-time technologies to enhance disaster preparedness and response.

IoT-enabled Flood Early Warning Systems (FEWS) have emerged as a transformative solution that integrates sensors, telemetry, wireless communication, and cloud-based analytics to deliver continuous monitoring of hydrological and meteorological variables [3, 16]. These systems enable rapid data acquisition and dissemination, improving the accuracy and timeliness of flood predictions and warnings.

Telemetry, as the backbone of IoT-based FEWS, refers to the automated collection, transmission, and analysis of data from remote or inaccessible locations to a central monitoring system. It combines sensors, communication networks, and data processing platforms to ensure real-time or near-real-time visibility of environmental and infrastructural performance [19]. The core components of telemetry include measurement devices that capture physical parameters such as temperature, flow rate, or pressure; transmission systems that relay data via wired or wireless technologies such as GSM, LoRaWAN, or satellite; and receiving platforms such as SCADA and dashboards that process and store the data. These are complemented by analytics and decision-support systems that interpret information for predictive maintenance, efficiency optimization, and automated control.

Telemetry has been applied across multiple sectors including energy systems for monitoring solar and wind performance, water and agriculture for irrigation and aquaculture management, telecommunications for tower and battery monitoring, transport for vehicle and aviation tracking, and environmental systems such as air quality and flood monitoring networks [12]. Depending on the application context, telemetry can be implemented through wired infrastructures for industrial reliability, wireless IoT-based solutions using GSM, Wi-Fi, ZigBee, LoRa, or NB-IoT, or satellite-based systems suitable for remote and inaccessible regions [8] Globally.

Kenya provides a critical case study due to its high vulnerability to recurrent flooding, particularly in regions such as the Tana River Basin, Nyando Basin, and Nairobi River Catchment [11]. Floods in these areas result in significant socio-economic losses, displacement of communities, and damage to critical infrastructure. Integrating IoT-based FEWS in Kenya not only addresses the weaknesses of conventional flood monitoring but also supports the country's disaster risk reduction strategies, as outlined in the National Disaster Risk Management Policy [13]. The adoption of telemetry-based FEWS aligns with global frameworks such as the Sendai Framework for Disaster Risk Reduction, promoting resilience and sustainable adaptation to climate-induced disasters.

2.Methodology

This desktop study adopted a systematic review approach to synthesize current knowledge on the use of Internet of Things (IoT) telemetry in Flood Early Warning Systems (FEWS). The methodology followed structured steps to ensure comprehensive coverage and reliability of findings.

Relevant literature was gathered from reputable scientific databases including Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar. Grey literature such as technical reports, government publications, and policy briefs was also considered to capture practical applications and case studies.

Keywords used in the search included: "Flood Early Warning Systems," "IoT telemetry," "wireless sensor networks flood monitoring," "Global and Kenya flood early warning," and "real-time hydrological monitoring." Boolean operators (and, or) were applied to refine search results.

Selected studies were systematically analyzed to extract information on system components (sensors, communication technologies, data processing tools, and dissemination channels), applications (geographic coverage, use cases, and performance), challenges and limitations, and opportunities for scaling IoT-enabled FEWS in developing contexts. A thematic analysis approach was applied, categorizing findings into global applications, Kenya-specific applications, and emerging challenges. Comparative synthesis highlighted similarities and differences across regions.

To ensure reliability, the review prioritized peer-reviewed sources and cross-checked findings from multiple references. Reports from authoritative bodies such as the United Nations Office for Disaster Risk Reduction (UNDRR), World Bank, and Kenya Meteorological Department (KMD) were included to validate technical and policy perspectives.

3.Results and Discussions

3.1 Traditional versus IoT-Based Flood Monitoring Approaches

Traditional flood monitoring approaches rely heavily on manual and semi-automated systems such as staff gauges, mechanical recorders, and field surveys. These systems have been widely used for decades to measure river water levels and rainfall, often requiring human intervention for data recording and reporting. Data is typically transmitted through analog communication channels such as radio or telephone lines, and warnings are issued based on statistical models and historical hydrological records [20; 22; 2]. While these methods have laid the foundation for flood forecasting, they often provide limited spatial coverage, delayed data reporting, and short lead times for issuing effective warnings, especially under the pressures of climate variability.

Ridwan [15] gives a systematic literature review of IoT-based flood early warning systems including IoT technologies have been developed and utilized for flood detection, their performance, and implementation challenges. The key findings indicate that ultrasonic sensors are widely adopted for real-time water level monitoring, often integrated with microcontrollers and communication modules such as NodeMCU. Alerting mechanisms, such as SMS or mobile app notifications, are common in deployed systems. However, the review also highlights persistent challenges: sensor power management, network connectivity reliability, energy efficiency, and scalability in diverse environmental settings [15]). The paper recommends further research into energy-efficient IoT devices, resilient communication designs, and integration of IoT systems with cloud platforms to support robust flood early warning.

A novel Flood Monitoring and Warning System (FMWS) that uses LoRaWAN technology to deliver low-power, wide-area connectivity for flood monitoring in catchment areas Zakaria and his colleagues [24]. The system centers around an HC-SR04 ultrasonic sensor connected to an Arduino microcontroller, which measures water levels and classifies risk into categories such as "safe," "alert," "cautious," or "dangerous." Data are transmitted through a custom LoRaWAN gateway to IoT platforms (The Things Network, TagoIO, ThingSpeak), displayed on multiple dashboards, and are solar-powered to ensure operation during power outages. They also evaluated communication performance metrics—RSSI (Received Signal Strength Indicator), SNR (Signal-to-Noise Ratio), Packet Delivery Ratio (PDR), and latency—using two spreading factors (SF7, SF12). The implementation demonstrating that the system was effective, user-friendly, and scalable, suitable for early warnings in flood-prone catchments under conditions of sparse infrastructure and limited resources.

Choosumrong [4] propose a low-cost, real-time water-level monitoring and flood early warning system that combines ultrasonic sensors deployed across a catchment with Geographic Information System (GIS) spatial analysis. The system collects continuous water level readings from multiple monitoring stations, integrates them with a 1-meter digital elevation model (DEM), and generates dynamic flood maps illustrating inundation zones, flood depth, and water volume per sub-catchment. Their prototype demonstrates that affordable IoT-based monitoring devices, when integrated with geospatial computation, can enable scalable, real-time flood situational awareness to enhance early warning, disaster preparedness, and water management in lowland agricultural areas.

A review of advanced sensor technologies (beyond conventional devices) for flood monitoring and damage, presented by Tao [18] such as radar, LiDAR, UAV-based remote sensors, pressure and ultrasonic sensors, and smart imaging systems. They discuss how these advanced technologies improve spatial resolution, accuracy, and resilience especially in challenging environments, and how they integrate with IoT, machine learning, and cloud platforms to enable real-time monitoring, early warning, and more precise flood impact magnitudes and extent (mapping) using low-cost radar and microwave sensors, unmanned aerial systems, and edge computing to reduce latency and improve alerting speed.

A number of researchers including Esposito [6] provide IoT architectures for deployment in early warning systems (EWS) for various natural disasters including floods, earthquakes, tsunamis, and landslides. They reviewed edge/fog and cloud-based IoT architectures alongside system components (sensors, communications technologies, prediction algorithms), typical constraints (latency, energy consumption, fault tolerance, coverage). They demonstrated how integrating Fog/Edge computing layers can reduce latency and enhance resilience, energy efficiency, and real-time responsiveness. They also identified the gaps including challenges that limit deployment in remote or harsh terrains, lack of redundancy in network design, and limited case studies that combine predictive analytics with heterogeneous sensor arrays and hence recommending future work through optimization of communication protocols, mission-tailored architecture, and enhanced use of edge computing to meet stringent latency and reliability demands in varied environments.

The Table 1 below summarises the major differences between the traditional and modern flood monitoring approaches.

Table 1: Traditional versus IoT-Based Flood Monitoring Approaches

Aspect	Traditional Flood Monitoring	IoT-Based Flood Monitoring (Modern FEWS)
Data Collection	Manual readings from staff gauges, mechanical recorders, and field surveys [20].	Automated sensors (water level, rainfall, soil moisture, weather stations) provide continuous data [3]
Transmission Method	Analog radio, telephone lines, or manual reporting to central stations [22]	Wireless networks (GSM, LoRaWAN, NB-IoT, Satellite) enable real-time telemetry [1].
Data Frequency	Periodic, often hours to days between updates.	Real-time or near real-time, updated every few seconds to minutes.
Forecasting Tools	Based on historical hydrological records and statistical models [2]	AI/ML predictive models, big data analytics, and cloud-based platforms [7].
Spatial Coverage	Limited; few monitoring stations covering large basins.	Dense networks of low-cost IoT sensors ensure wider coverage, including remote areas.
Lead Time for Warnings	Often short and insufficient for effective evacuation.	Longer lead times due to real-time monitoring and predictive modeling.
Community Engagement	Alerts via local authorities, sometimes delayed.	Multi-channel alerts via SMS, mobile apps, USSD, radio, and dashboards [19].
Limitations	Delayed reporting, low accuracy under changing climate, costly maintenance of manual systems.	Connectivity gaps in rural areas, cybersecurity risks, and high initial deployment costs.

3.2 Components IoT-Enabled (Modern) Flood Early Warning Systems

IoT-enabled Flood Early Warning Systems (FEWS) rely on an interconnected framework of sensors, telemetry networks, data processing platforms, and alert dissemination mechanisms. These components collectively enable real-time monitoring, predictive analysis, and timely communication of flood risks to authorities and communities. Understanding these system components is critical for designing robust and scalable FEWS both globally and in Kenya.

3.2.1 Sensors and Measurement Devices

Sensors form the foundation of IoT-enabled FEWS, providing real-time measurements of hydrological and meteorological parameters. Commonly deployed sensors include ultrasonic water level sensors, tipping-bucket rain gauges, soil moisture probes, flow meters, and automated weather stations (AWS) [3, 7]. In urban and riverine flood-prone areas, additional sensors such as CCTV cameras and infrared or radar flow sensors can supplement water-level data, improving spatial coverage and situational awareness [6].

In Kenya, pilot deployments in the Nyando Basin and Tana River Basin utilize water level sensors and rainfall gauges integrated with GSM telemetry, providing near-real-time data to county disaster centers. These sensor networks have improved lead times for early warning by several hours, enabling timely evacuation and risk mitigation [11, 9].

3.2.2 Telemetry and Communication Networks

Telemetry refers to the automatic transmission of sensor data from remote sites to centralized servers for monitoring and analysis. Various communication technologies are applied depending on terrain, cost, and reliability requirements. GSM/GPRS/3G/4G networks are widely used in Kenya and Sub-Saharan Africa for river basins and peri-urban monitoring, providing sufficient coverage for sensor nodes [9].

For rural or inaccessible regions, LoRaWAN (Long Range Wide Area Networks) offers low-power, long-range, and cost-effective communication between multiple sensor nodes and a central gateway [1]. Satellite telemetry (e.g., Iridium, Inmarsat) is deployed in highly remote or off-grid areas, while radio frequency (RF) telemetry is sometimes used for localized flood monitoring in urban settings [20]. Globally, IoT FEWS in countries such as India, Brazil, and the Netherlands integrate a combination of GSM, LoRaWAN, and satellite telemetry to optimize coverage and reliability [15, 4].

3.2.3 Data Processing Platforms and Analytics

Once collected, sensor data are transmitted to cloud servers or centralized platforms where they are stored, cleaned, and analysed. Modern FEWS employ big data analytics and AI/ML-based predictive models (including HEC-RAS, SWAT, or machine learning flood forecasting models) to predict flood onset, magnitude, and spatial extent [5, 7]. Edge computing at gateways can pre-process data to reduce transmission load, improve response times, and enhance system efficiency.

Globally, predictive analytics integrated with IoT telemetry have been shown to reduce flood response times by 20–40% in pilot implementations in Sri Lanka, Brazil, and the Netherlands [12, 19]. In Kenya, cloud-based dashboards are increasingly used to visualize real-time river levels and rainfall intensities enabling some local County Disaster Management Teams to make informed decisions on flood alerts and resource allocation to avert related disasters [13].

3.2.4 Alert Dissemination Systems

The final component of IoT-enabled FEWS is the communication of alerts to stakeholders, authorities, and at-risk communities. Alerts can be disseminated via SMS, USSD, mobile applications, web dashboards, GIS-based flood maps, email notifications, or community FM radios [3]. Multi-channel communication ensures redundancy and maximizes reach, particularly in areas with limited digital penetration.

Globally, systems in India and Europe use similar multi-channel dissemination strategies to ensure timely alerts, often integrating automated triggers when water levels exceed critical thresholds [6, 2]. In Kenya, Nyando and Tana River basin projects employ SMS alerts and local FM radio broadcasts alongside dashboards for county officers. Urban deployments in the Nairobi River Catchment additionally leverage mobile apps and social media channels to inform residents in informal settlements [17].

3.2.5 Integration of Components

The effectiveness of IoT-enabled FEWS depends on the seamless integration of sensors, telemetry, data processing, and alert dissemination. Real-time data collection via sensors, efficient transmission through telemetry, predictive analytics at the processing layer, and multi-channel alert dissemination collectively reduce the time between hazard detection and community response. Proper integration also allows authorities to prioritize interventions, manage resources, and plan evacuation routes, thus enhancing resilience to flood disasters.

3.3 Challenges and Opportunities in IoT FEWS

3.3.1 Challenges in IoT FEWS

Despite the growing adoption of IoT-based telemetry in Flood Early Warning Systems (FEWS), several technical, operational, and socio-economic challenges persist. From a technical perspective, system reliability is a critical concern. Sensor networks deployed in flood-prone regions may suffer from signal loss, battery depletion, or physical damage due to extreme weather events [1]. Telemetry systems relying on GSM or LoRaWAN networks can face intermittent connectivity in remote or densely forested areas, reducing the timeliness and accuracy of alerts [7]. Furthermore, integrating heterogeneous sensors and communication protocols into a unified platform requires sophisticated data management and interoperability standards [6].

Operational and socio-economic challenges include the high initial costs of deploying IoT infrastructure, limited technical capacity for system maintenance, and lack of awareness or digital literacy among local communities [9]. In Kenya, many flood-prone rural areas still lack sufficient GSM coverage or electricity, which constrains the sustainability of sensor networks [13]. Cybersecurity is also a growing concern; IoT systems are vulnerable to data tampering, spoofing, and unauthorized access, which could compromise early warning accuracy [14].

3.3.2 Opportunities for IoT-Enabled FEWS

Despite these challenges, IoT telemetry presents significant opportunities to enhance flood resilience. Real-time monitoring and predictive analytics allow early identification of flood risks, improving the lead time for evacuation and emergency response [3]. Multi-channel alert dissemination through SMS, mobile applications, and community radios ensures inclusive communication, reaching both urban and rural populations.

Globally and including Kenya, the integration of IoT-based FEWS aligns with the international and national digital transformation agenda, providing opportunities for public-private partnerships to deploy low-cost, scalable sensor networks in underserved regions [15, 26]. Open-source IoT platforms and low-power communication protocols, such as LoRaWAN and NB-IoT, offer affordable alternatives for rural flood-prone areas, allowing community-managed monitoring systems to complement official disaster management efforts [8].

Globally, lessons from countries like India, Sri Lanka, and the Netherlands indicate that multi-level integration—linking local, regional, and national monitoring networks—enhances the effectiveness of FEWS and improves coordination among stakeholders [11, 2]. This suggests that FEWS could benefit from the integration of IOT and related systems in the following, among other factors:

1. Redundancy in sensor networks: Deploying multiple sensors and communication channels ensures reliability in case of node failure.
2. Community engagement: Educating and involving local populations increases the uptake and effectiveness of early warnings.
3. Low-cost and sustainable design: Using solar-powered sensors and open-source telemetry platforms reduces operational costs and enhances long-term sustainability.
4. Data-driven decision-making: Integrating telemetry data with predictive models and GIS-based flood mapping improves situational awareness and resource allocation.

4.Conclusion and Recommendations

Flood Early Warning Systems (FEWS) enhanced with IoT telemetry represent a transformative approach to flood risk management. By integrating real-time sensors, telemetry networks, cloud-based data processing, and multi-channel alert dissemination, IoT-enabled FEWS improve the timeliness and accuracy of flood warnings. Global experiences from countries such as India, Sri Lanka, Brazil, and the Netherlands demonstrate that IoT telemetry reduces response times, enhances situational awareness, and supports evidence-based decision-making during flood events [2, 4, 11].

Globally some of the countries that experience frequent flooding, include Bangladesh (especially the Ganges-Brahmaputra-Meghna delta, which reports severe seasonal floods almost every year due to monsoon rains [25]; India (in states like Bihar and Assam, primarily caused by heavy monsoon rainfall and overflowing rivers such as the Brahmaputra and Ganges [26] and United States (along the Mississippi River Basin and coastal States like Louisiana, due to hurricanes and river surges) [6]. In these Countries advanced IoT-enhanced FEWS are in use. In Kenya, pilot deployments in the Tana River Basin, Nyando Basin, and Nairobi River Catchment show that IoT-based FEWS can improve lead times for evacuation, increase community preparedness, and strengthen resilience to both rural and urban floods [9, 7]. However, challenges such as high initial costs, limited technical capacity, connectivity gaps, and community engagement constraints need to be addressed to scale these systems nationally.

Key recommendations for enhancing IoT-enabled FEWS include:

1. Promoting low-cost, sustainable sensor networks: Adoption of solar-powered sensors and open-source telemetry platforms can reduce operational costs and ensure long-term sustainability.
2. Strengthening capacity and technical expertise: Training programs for county disaster management teams, engineers, and community volunteers are essential to maintain, calibrate, and operate IoT FEWS effectively.
3. Expanding connectivity in rural and remote areas: Utilizing low-power wide-area networks (LoRaWAN, NB-IoT) or satellite telemetry can enhance coverage where GSM networks are weak or absent.
4. Integrating multi-agency data systems: Linking Kenya Meteorological Department (KMD), Water Resources Authority (WRA), and county disaster management platforms ensures coordinated, timely, and actionable flood warnings.
5. Enhancing community engagement and awareness: multi-channel alert systems, including SMS, USSD, mobile applications, and community radios, should be complemented with educational programs to ensure that early warnings are understood and acted upon promptly.
6. Leveraging predictive analytics and AI: Integrating telemetry data with machine learning-based forecasting models can improve flood prediction accuracy and support proactive disaster management decisions.

In conclusion, IoT telemetry offers a robust, scalable, and cost-effective pathway for flood early warning in Kenya and other developing countries. By addressing technical, operational, and socio-economic challenges, Kenya can build resilient flood monitoring infrastructure that reduces human, social, and economic losses. Future research should focus on optimizing low-cost sensor networks, integrating cross-basin data for regional early warning, and developing community-centred deployment models to ensure sustainable adoption.

References

[1] Adelantado, F., Vilajosana, X., Tuset-Peiro, P., Martinez, B., Melia-Segui, J., & Watteyne, T. (2017). Understanding the limits of LoRaWAN. IEEE Communications Magazine, 55(9), 34–40. https://doi.org/10.1109/MCOM.2017.1600613
[2] Alfieri, L., Burek, P., Dutra, E., Krzeminski, B., Muraro, D., Thielen, J., & Pappenberger, F. (2019). GloFAS – global ensemble streamflow forecasting and flood early warning. Hydrology and Earth System Sciences, 23(1), 1–17. https://doi.org/10.5194/hess-23-1-2019
[3] Asfaw, A., & Dargahi, B. (2021). IoT-based flood early warning systems: Opportunities and challenges. Water, 13(11), 1530. https://doi.org/10.3390/w13111530
[4] Choosumrong, S., Piyathamrongchai, K., Hataitara, R., Soteyome, U., Konkong, N., Chalongsuppunyoo, R., Raghavan, V., & Nemoto, T. (2025). Development of an IoT-based flood monitoring system integrated with GIS for lowland agricultural areas. Sensors, 25(17), 5477. https://doi.org/10.3390/s25175477
[5] Deltares. (2019). Flood early warning systems in the Netherlands: Integration of telemetry and predictive analytics. Delft: Deltares.
[6] Esposito, M., Palma, L., Belli, A., Sabbatini, L., & Pierleoni, P. (2022). Recent advances in Internet of

Things solutions for Early Warning Systems: A review. Sensors, 22(6), Article 2124. https://doi.org/10.3390/s22062124

[7] Guo, Q., Li, X., & Zhang, L. (2021). Real-time flood forecasting with IoT telemetry and hydrological models: A case study of Yangtze River Basin, China. Journal of Hydrology, 603, 126870. https://doi.org/10.1016/j.jhydrol.2021.126870

[8] Horita, F. E., Sousa, F. M., de Freitas, E. P., & Cerri, L. (2017). IoT-based flood monitoring and warning systems: Review and perspectives. Journal of Sensors, 2017, 123–134. https://doi.org/10.1155/2017/7896174

[9] Li, S., Xu, L., & Zhao, S. (2022). IoT-based real-time flood monitoring and early warning: Architecture and implementation. Environmental Modelling & Software, 149, 105345. https://doi.org/10.1016/j.envsoft.2022.105345

[10] Mekonnen, A., Tilahun, S., & Gebreslassie, B. (2022). Community-based IoT flood monitoring systems in Ethiopia: Lessons and prospects. International Journal of Disaster Risk Reduction, 77, 103024. https://doi.org/10.1016/j.ijdrr.2022.103024

[11] Mwaura, F., & Nyongesa, J. (2019). Integrating ICT in disaster risk reduction: Flood Early Warning Systems in Kenya. International Journal of Disaster Risk Science, 10(3), 345–356. https://doi.org/10.1007/s13753-019-00229-7

[12] Mutua, J., & Klik, A. (2022). Climate change and flood risk in Kenya: Implications for disaster risk management. Environmental Science & Policy, 123, 1–12. https://doi.org/10.1016/j.envsci.2021.11.007

[13] Onywere, S. M., Getenga, Z. M., & Opiyo, J. (2018). Flood hazards and management approaches in Kenya. Journal of Environmental Planning and Management, 61(6), 1072–1092. https://doi.org/10.1080/09640568.2017.1370543

[14] Republic of Kenya. (2018). National Disaster Risk Management Policy. Nairobi: Government Press.

[15] Ridwan, I. F. (2023). Internet of Things development for flood early warning monitoring system: A review. Journal of Computation Physics and Earth Science (JoCPES), 3(1). https://doi.org/10.63581/JoCPES.v3i1.01

[16] Saini, R., Sharma, A., & Singh, D. (2020). IoT-based flood monitoring system: Lessons from India. Journal of Water and Climate Change, 11(4), 1200–1215. https://doi.org/10.2166/wcc.2020.203

[17] Shukla, A., Patel, K., & Kumar, A. (2020). IoT telemetry in flood warning systems: A review. International Journal of Advanced Research in Engineering and Technology, 11(3), 45–60.

[18] Tao, Y., Tian, B., Adhikari, B. R., Zuo, Q., Luo, X., & Di, B. (2024). A review of cutting-edge sensor technologies for improved flood monitoring and damage assessment. Sensors, 24(21), 7090. https://doi.org/10.3390/s24217090

[19] UN-Habitat. (2020). Urban flood resilience in Nairobi: Integrating IoT and community early warning systems. Nairobi: UN-Habitat.

[20] United Nations Office for Disaster Risk Reduction (UNDRR). (2020). Early warning systems: A checklist. Geneva: UNDRR.

[21] World Bank. (2020). Building resilience to flood hazards in Kenya: Policy and practice. Washington, DC: World Bank.

[22] World Meteorological Organization (WMO). (2021). Guidelines on flood early warning systems. Geneva: WMO.

[23] Zahri, R., Ali, A. H. M., Rambat, S., Ghazali, N. H., Ahmad, Y., & Hamzah, M. H. (2025). Flood Early Warning Systems (FEWS) in enhancing disaster risk reduction and community resilience: A systematic review. International Journal of Law, Government and Communication, 10(40), 425–445. https://doi.org/10.35631/IJLGC.1040031

[24] Zakaria, M. I., Jabbar, W. A., & Sulaiman, N. (2023). Development of a smart sensing unit for LoRaWAN-based IoT flood monitoring and warning system in catchment areas. Internet of Things and Cyber-Physical Systems, 3, 249–261. https://doi.org/10.1016/j.iotcps.2023.04.005

[25] World Bank. (2020b). Bangladesh flood risk management: Building resilience in a changing climate. Washington, DC: World Bank.

[26] Hashemi-Beni, L., Puthenparampil, M., & Jamali, A. (2024). A low-cost IoT-based deep learning method of water gauge measurement for flood monitoring. Geomatics, Natural Hazards and Risk, 15(1), 2364777. https://doi.org/10.1080/19475705.2024.2364777

[27] United Nations Office for Disaster Risk Reduction. (n.d.). What is the Sendai Framework? UNDRR. Retrieved July 1, 2025, from https://www.undrr.org/implementing-sendai-framework/what-sendai-framework